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EVALUATION OF LASER-PROTECTIVE EYEWEAR DYES IN UVEX LENSES

by

Leonard A. Levasseur, Joseph F. Roach, and Kathryne B. Brubaker

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UNITED STATES ARMY NATICK
RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
NATICK, MASSACHUSETTS 01760-5000

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Leonard A. Levasseur, Joseph F. Roach
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Twenty-seven lenses of various dye combinations were received for testing from Uvex Corp. A previous contract from Uvex for Natick had failed the 240-hour Weatherometer test and this study was to determine which dye or which combination of dyes was responsible for this degradation. Dyes from different suppliers were incorporated into Uvex polycarbonate lenses. These dyes were laser blocking dyes obtained from Gentex, Polaroid, Barnes, Steadfast and Epolin (a Uvex dye) and used in various combinations within the lenses. These lenses were evaluated for optical density, visual transmittance, laser saturation, and solarization. Some of the lenses were tested in the weatherometer only.

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PREFACE

This study of 27 lenses of various dye combinations in Uvex Corporation lenses was undertaken during the period March 1992 to June 1992 by the authors at the US Army Natick Research, Development and Engineering Center. The funding was Program Element 0602786A, Project AH98, Task AOO and Work Unit CAO.

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EVALUATION OF LASER PROTECTIVE EYEWEAR DYES IN UVEX LENSES

SUMMARY

Twenty-seven lenses for eye protection containing a combination of commercial dyes that were developed to absorb specific laser lines were tested for the following properties: optical density at the laser lines, laser saturation and resistance to weathering. The lenses were received from Uvex Corp and contained dyes from the following suppliers; Gentex Corp, Polaroid, EDO Barnes, Steadfast, Uvex and Epolin. Each dye was used in the Uvex spectacle configuration and was tested according to specifications MIL-STD-810E[1] Procedure II for solarization effects and optical density specifications as in MIL-G-0043914E(GL).[2]

1.0 INTRODUCTION

Dyes used as laser beam attenuators have been a major part of the laser eye protection program at Natick. The physical and environmental requirements imposed on dye performance criteria have proven difficult to achieve. Consequently, many types of dyes were developed that attempted to provide the required protection in a ballistic substrate that met all the specifications for laser eye protection for the individual soldier. This study of dye performance was initiated to determine the characterisics of each dye pertaining to test requirements and to compare the measured values with the specifications.

In addition this study was undertaken to characterize the synergistic properties of dye combinations in a polycarbonate substrate as used in the Uvex spectacle. The usual test criteria were adhered to in the evaluation of the durability and protective properties of the laser-protective lens materials. The results of this study will provide guidance on the selection of the product to employ in the construction of protective eyewear to ensure proper protection for the wearer.

2.0 TEST PROCEDURES

a. PROPERTIES EVALUATED

In conformance with requirements, the following tests were performed by personnel from the U.S Army Natick Research Development and Engineering Center (NATICK), Science & Technology Directorate (S&TD), Fiber and Polymer Science Division (F&PSD), Technology Application Branch (TAB).

1. Spectrophotometric measurements of optical density and visual transmittance (photopic and scotopic).
2. Weatherometry: Resistance to solar radiation.
3. Laser Saturation: The measure of optical density change as a function of laser intensity.

b. INSTRUMENTATION/METHOD

The optical density of each sample is measured on a Perkin-Elmer Lambda 9 Spectrophotometer, Serial No. 1733. The Lambda 9 is a Double Monochromator, Double Beam Ratio Recording UV/VIS/NIR Spectrometer, which is capable of providing accurate photometric readings between 4 and 5 absorbance units directly. For lenses with relatively high absorbance values, a baseline correction is made using neutral density filters. Transmittance measurements (%T) are measured using the Perkin-Elmer Lambda 9 in the transmission mode, and the scotopic and photopic values are obtained using software developed at Natick.

The weatherometer studies are made using an Atlas Weatherometer Model Ci35 with controlled irradiance. The test setup and procedures are in conformance with those prescribed in MIL-STD-810E, Method 505.2, Procedure II.[1] The following test parameters and cycling times are used:

Irradiance level: 0.35 $W/m^2/nm$, measured at 340 nm.

Weathering cycle: 20 hours of irradiation followed by 4 hours of darkness, repeated for 10 cycles.

Filtering: a borosilicate inner filter with a borosilicate (Type S) outer filter.

Temperature: 120° F (48° C) during the light portion of the cycle, and uncontrolled during the dark portion of the cycle.

Laser saturation measurements are made using the following instrumentation and criteria.

Laser: Custom built Q-switched Ruby/YAG laser manufactured by Continuum Corp, having an output of 75 mJ at 6943 nm (ruby) with a pulse width of 30 ns; 750 mJ at 1.06 micrometer with pulsewidths of 10, 20 and 30 ns; and 300 mJ at 532 nm with pulsewidths of 10, 20 and 30 ns.

Detector System:

Molectron JD2000 Joulemeter Ratiometer Display (S/N 1155)

Molectron J_{3S-10} Joulemeter (S/N 162)

Molectron J_{3-09} Joulemeter (S/N 392)

Molectron J-25 Joulemeter (S/N 962)

Newport FS-3 ND Filters (S/N 739)

Big Sky Software Corporation Multicam 2.1 Beam Diagnostic System

Cohu Solid State Charge Couple Device (CCD) Camera, Model 4800 (S/N 180811)

Figure 1 depicts the setup used in making saturable absorption measurements. By placing different combinations of neutral density (ND) attenuating filters at the laser output aperture, the user can vary the incident energy at the sample. ND filters also protect the reference detector and the CCD camera from damage. Another protective filter is placed at the throughput detector during baseline measurements or when a sample does not adequately attenuate the laser energy. A uniform energy distribution (top hat) is attained from a Gaussian distribution by a pair of lenses and an aperture. The beam is expanded with a plano-concave lens (f=-51.4 mm) and then recollimated by a plano-convex lens (f=97.5 mm) placed at a distance, d, equal to the sum of the two focal lengths (d=46.1 mm). A fixed diameter (5 mm) aperture placed prior to the sample limits the impinging radiation to that of a top hat energy distribution with a known area (0.196 cm^2).

After the optical components are aligned, the beam profile is optimized by placing a CCD camera at the laser output. While monitoring the output beam, the laser cavity is adjusted to produce a near Gaussian distribution. The camera is then moved to the throughput detector's position to verify a top hat distribution at the sample. The throughput detector is subsequently returned to its position in the optical path. Pulse width is determined by a photodetector and oscilloscope.

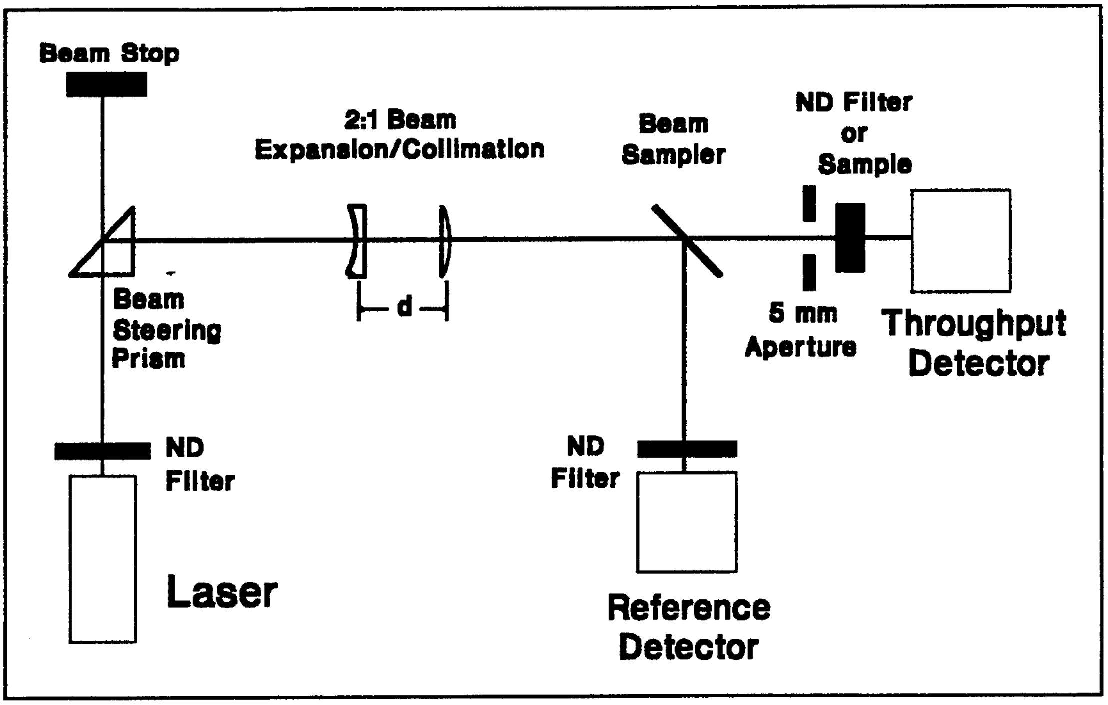


Figure 1. Saturable Absorption Setup

The requirement contained in MIL-STD-810E[1] mandates that each sample will be tested at 1MW/cm² without degrading the optical density to a value below that required by the specification. The test procedure is as follows. The incident energy is calculated according to (eqn. 1):

$$E = I * t_p * A \tag{1}$$

where,

E = incident energy (J)

I = irradiance on the sample (MW/cm²)

t_p = pulse duration (seconds)

A = area (cm²)

The required incident energy density (approximately 2 mJ over an area of 0.196 cm²) is attained by trial and error combinations of ND filters at the laser output aperture. The pulse width used is 10ns to give approximately 1MW/cm². A baseline measurement is established by averaging the energy at the reference and the throughput detectors for 25 shots. Due to damage threshold limits on the detector, a ND filter is sometimes required in front of the throughput detector during baseline measurements. The protective ND filter is replaced with a sample of unknown optical density (OD) and the energy at the two detectors is again recorded and averaged for 25 shots.

Optical density is defined by (eqn. 2):

$$\mathbf{OD = \log_{10}(1/T)} \tag{2}$$

where T is the measured transmission (output/input).

A normalization constant, k, is calculated by (eqn. 3):

$$\mathbf{k = E_r/E_{r'}} \tag{3}$$

where E_r = average reference energy during baseline measurement (J)

$E_{r'}$ = average reference energy during sample measurement (J)

The OD of the sample is then calculated by (eqn. 4):

$$\mathbf{OD = A + \log(k^*(E_t/E_{t'}))} \tag{4}$$

where k = normalization constant defined above

A = OD of ND filter at sample detector during baseline measurement

E_t = average throughput energy during baseline measurement (J)

$E_{t'}$= average throughput energy during sample measurement (J)

A value of the optical density lower than that obtained with the spectrophotometer would indicate the occurrence of saturable absorption.

3.0 RESULTS

Table 1 shows the results obtained in testing for optical characteristics. These include optical densities, tested under low power using the Perkin Elmer Lambda 9 Spectrophotometer and under high power using laser radiation, scotopic and photopic transmittances and weatherometer tests. Multiple manufacturers as noted in the table represent dyes for L1, L2 and L3 in that order.

a. OPTICAL DENSITY (LOW POWER IRRADIATION)

Table 1 shows the optical densities measured with the Lambda 9 spectrophotometer. A representative spectrum is shown in Figure 2. Curve A is the spectrum before weatherometer testing and B after.

The majority of the samples met the initial optical density requirement of 4.0 or greater. However, samples #006, 035,062, 063, 068 and 069 fell below this level at one or more of the required wavelengths. In the measurement of optical density a difference was noted from that reported by Uvex. Further investigation showed that by repositioning the lens, an optical density of equal or greater than that reported from Uvex was found. For instance, measurement of sample #060 showed a difference of 0.74 OD units at 1064 nm over the front surface. Several of the other samples also exhibited similar differences.

Table 1. Optical Density, Laser Saturation, Solarization Test Results (nm)

SMP	LAMBDA 9			LASER SATURATION			WEATHEROMETER			TRANSM %		MFG*
	532	694	1064	532	694	1064	532	694	1064	PHOT	SCOT	
002	4.6	----	----	4.3	----	----	----	----	----	36	17	B
003	4.0	----	----	>4	----	----	----	----	----	48	8	B
005	4.0	----	----	----	----	----	4.1	----	----	----	----	U
043	4.3	----	----	----	----	----	4.4	----	----	29	16	S
010	----	5.7	----	----	3.1	----	----	5.8	----	64	77	S
025	----	----	3.9	----	----	3.8	----	----	3.5	36	28	E
032	----	----	4.9	----	----	----	----	----	3.6	----	----	P
054	----	----	5.6	----	----	>5	----	----	4.8	43	30	E
055	----	----	5.4	----	----	>5	----	----	4.8	17	11	E
058	----	----	4.4	----	----	4.5	----	----	3.9	18	12	E
059	----	----	5.4	----	----	>5	----	----	4.7	46	33	E
060	----	----	4.3	----	----	4.6	----	----	4.1	27	17	E
063	----	----	3.2	----	----	3.3	----	----	----	22	21	S
026	4.2	5.4	----	----	----	----	4.0	5.4	----	13	12	S
006	4.4	----	3.4	----	----	----	4.3	----	3.1	22	3	P
076	4.1	----	4.4	----	----	----	1.9	----	2.3	----	----	G
027	----	6.0	5.5	----	>4	>5	----	5.9	4.8	16	12	S/E
031	----	5.8	5.1	----	----	----	----	5.1	4.1	----	----	P
071	----	5.1	5.1	----	3.6	3.9	----	5.1	5.2	25	27	P
030	4.7	5.9	5.0	----	----	----	4.6	5.3	4.5	----	----	P
035	4.6	6.0	2.8	----	----	----	4.6	6.1	2.7	----	----	UGG
044	4.5	3.8	4.9	----	----	----	4.5	3.8	4.9	----	----	USE
062	3.3	5.4	5.2	----	----	----	2.9	5.0	5.2	----	----	BBE
068	4.8	5.2	2.9	>4	4.0	3.1	4.9	5.3	3.2	3	1	SSE
069	4.1	5.5	1.5	4.1	>4	1.6	3.8	5.8	1.8	6	3	SGG
070	4.0	6.1	4.0	3.9	>4	3.2	3.3	5.0	3.2	8	6	SSP
072	4.1	5.1	4.6	4.4	4.3	3.6	4.2	5.0	4.2	12	3	P

*B=EDO BARNES; U=UVEX; G=GENTEX; P=POLAROID; E=EPOLIN; S=STEADFAST

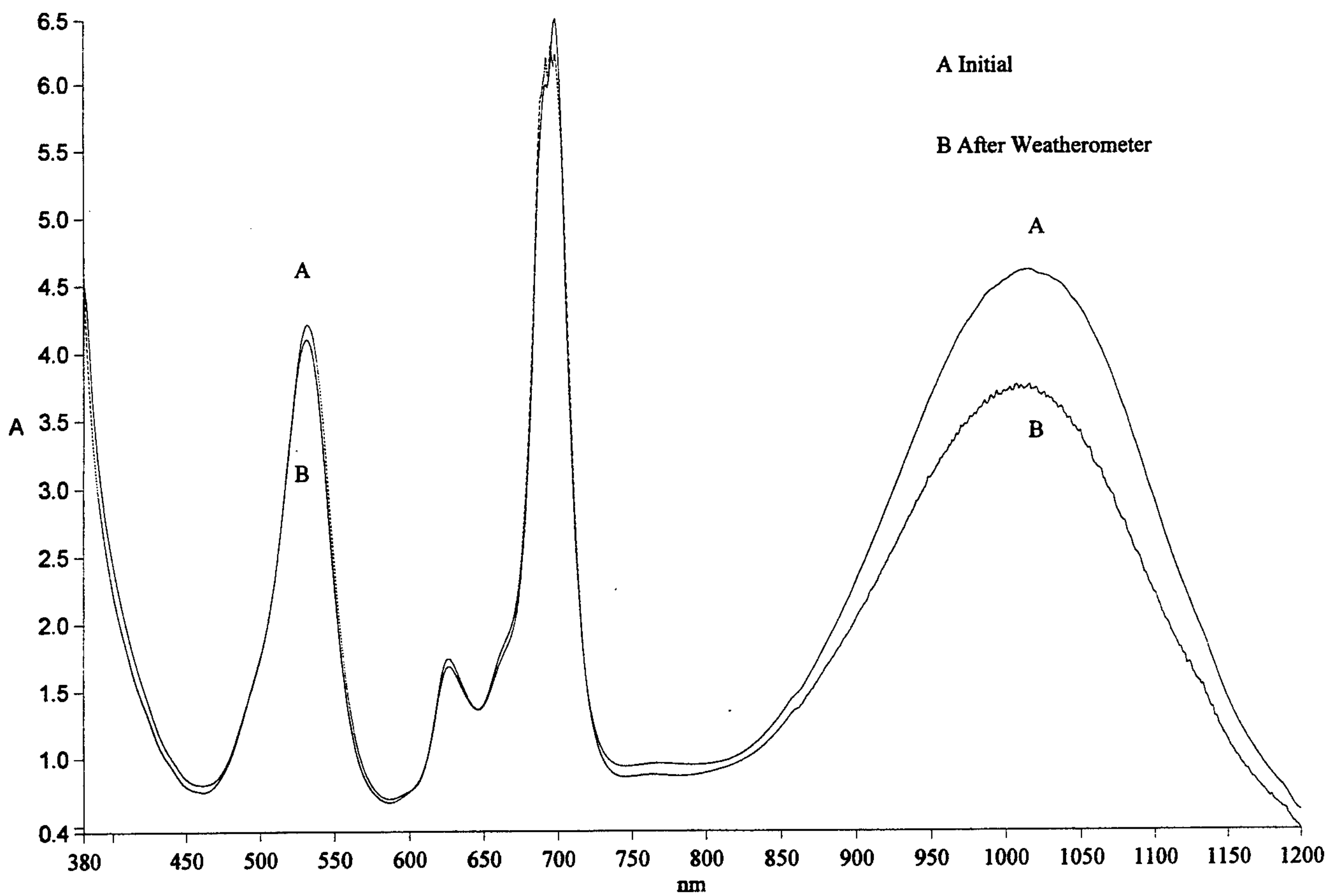


Figure 2. Representative Spectra of Optical Density vs Wavelength for Sample # 070. Curve A is Before Weatherometer Test and B After.

The optical density of sample #060 in particular, was measured at four locations along the right lens and left lens with the following results (Table 2):

Table 2. Optical Density of Sample 060

position	left lens	position	right lens
1	4.90	1	4.29
2	4.95	2	4.37
3	5.03	3	4.61
4	4.94	4	4.65

The variation in optical density (absorbance) for this sample ranged from 4.29 to 5.03. These results indicate that the dye was not distributed evenly in the polycarbonate.

b. OPTICAL DENSITY (HIGH POWER IRRADIATION)

Sixteen of the lenses were tested for laser saturation. Sample 010 showed a loss of greater than 2.5 optical units when tested at 694 nm. Samples 071 and 072 were affected at both 694 and 1064 nm, and 068 at 694. In no instance was the optical density at 532 nm affected.

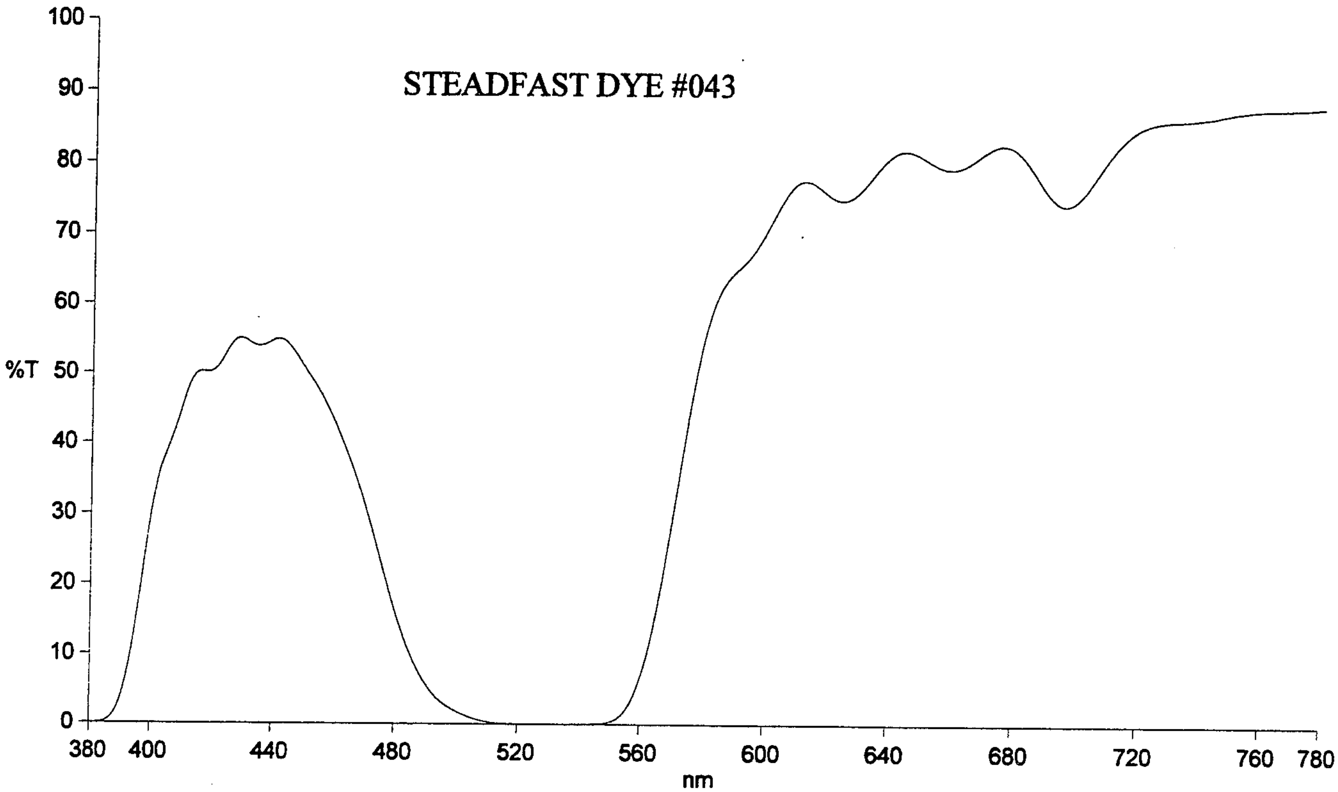
c. VISUAL TRANSMITTANCE

Values for photopic and scotopic (PHOT,SCOT) transmittances are shown in Table 1. Transmission curves for two samples (Figure 3) are typical examples of data used in calculating transmittance values.

The photopic transmittance relates to day vision and the scotopic to night vision. The critical parameter for visual transmittance is the scotopic value since reduction of light during the day is sometimes desired. As a general rule, transmittances of 40% or better are accepted as useful for both day and night use. As can be seen from the data in Table 1, current dye technology precludes its use for eye protection for both day and night operation due to the very low transmittances in three line configurations. In fact, the only sample in table I that meets the 40% criteria is for single laser line attenuation (sample 010) but this sample did not meet the optical density requirement when tested for saturation.

d. SOLARIZATION

Twenty four of the lenses were exposed in the weatherometer for 240 hours (10 days). Of the 13 lenses tested at 532 nm, samples 076 and 070 were significantly affected by solarization (loss of 0.5 optical density units or greater). At 1064 nm, 10 of the lenses lost 0.5 to 2 in optical density units. In some cases this would not have excluded the use of these dyes since the optical density remained over 4.0 and would have met the requirement. However, it does point out the susceptibility of the 1064 dye to fading and hence should be monitored for compliance with the specifications. At 694 nm three samples, 031, 030 and 070, were significantly affected. However all three remained over the required optical density of 4.0.



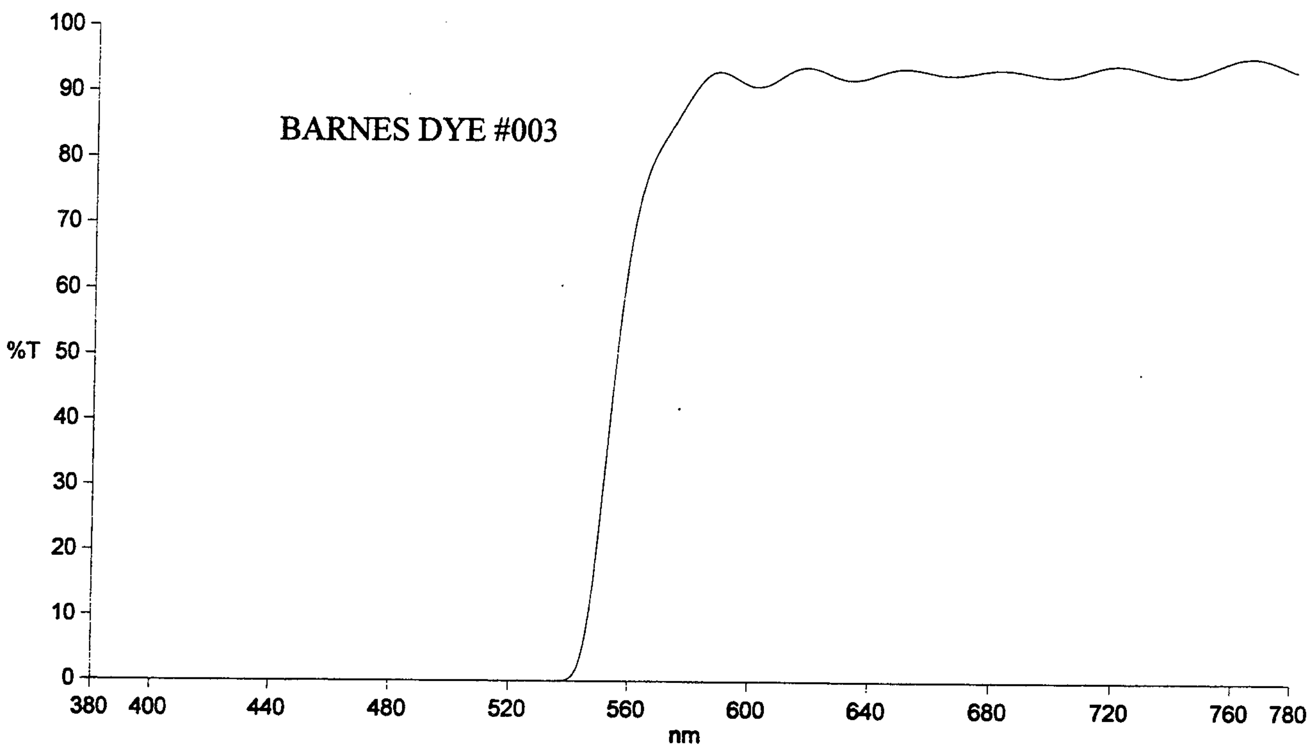


Figure 3. Transmission Spectra Used for Measuring Photopic and Scotopic Transmittances.

4.0 CONCLUSIONS

The object of this report is to initiate a data base study on the performance of various dyes as laser line attenuators. In addressing the optical densities necessary for laser eye protection in a ballistic substrate, the lenses performed as expected. The data accumulated point out the deficiencies of certain dyes alone as well as of some dye combinations in laser saturation testing and solarization. It is difficult to assess all the ramifications inherent in combining different dyes because of the differences noted in the performance of materials from the same manufacturer. For example, sample 032 from Polaroid showed a significant decrease in the optical density of the 1064 nm dye after testing in the weatherometer. Yet the same test on sample 006, another Polaroid sample but with attenuation for two wavelengths 532nm and 1064 nm, did not show significant changes. It would have been easier to assume a synergistic effect from the combination of the 532 nm and 1064 nm dyes if the initial optical densities at 1064nm had been the same. In any case, there is evidence that synergism in dye combinations affects the performance of the individual dyes.

REFERENCES

1. Department of Defense, MIL-STD-810E, Solar Radiation, 14 July 1989.

2. Department of Defense, MIL-G-0043914E(GL), Goggles, Sun, Wind and Dust, 26 Nov 1990.

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